N92-10857

STYLES OF EJECTA EMPLACEMENT UNDER ATMOSPHERIC CONDITIONS; P.H. Schultz, Geological Sciences, Brown University, Providence, RI 02912.

Although small in scale, laboratory experiments provide essential first-order constraints on processes affecting ballistic ejecta and styles of ejecta emplacement under different atmospheric environments at planetary scales. The NASA-Ames Vertical Gun allows impacting different fine-grained particulate targets under varying atmospheric pressure and density (different gas conditions), thereby helping to isolate controlling variables. Previous reports described general phenomena associated with the dynamic interactions with implications for Mars (1, 2, 3), Earth (4), and Venus (1, 5). Further analysis now permits characterizing distinct modes of emplacement that reflect the degree of ejecta entrainment within a turbidity flow created by ejecta curtain movement through the atmosphere.

Laboratory experiments establish that target material is ballistically ejected in response to the mechanical transfer of energy/momentum from the impactor to the target regardless of an atmosphere. Nevertheless, the presence of an atmosphere can change the ejection angle as atmospheric pressures increase. Comparison of high frame rate imaging for impacts under different densities reveals that this ejection angle is at least partly controlled by the ratio of aerodynamic drag to gravitational forces. As this ejecta curtain advances, it creates a characteristic circulation within the atmosphere, and aerodynamically decelerated fine-grained ejecta (for a given atmospheric density and crater size) become entrained in this atmospheric response (1, 2, 3). With increasing atmospheric density, increasing amounts of ejecta become entrained, and the late-stage ejecta curtain becomes severely distorted in comparison with the conical curtain under vacuum conditions. Additionally, a systematic change in ejecta emplacement styles occurs with increasing atmospheric pressure (2,3). For compacted pumice targets (median grain size of 80μ), a distinctive contiguous ridge is formed on the ejecta deposits for atmospheric pressure as low as 0.1 bars. As atmospheric pressure increases, the contiguous ejecta ridge (termed a "rampart") forms at greater distances from the rim. Atmospheric pressures exceeding about 0.5 bars typically result in the formation of individual ejecta lobes exhibiting even greater run-out distances (over 10 crater radii). Still greater pressures (1 bar) result in radially scoured inner ejecta facies and a distinctive near-rim moat, with distal ejecta lobes becoming very thin and dispersed. This systematic change can be correlated with the reduction in cratering efficiency.

Underlying processes controlling this systematic change in emplacement style can be identified by observing the evolution of the ejecta curtain, by changing target materials (including layered targets and low-density particulates), by varying atmospheric density, by changing impact angle, and by comparing the ejecta run-out distances with first-order models of turbidity flows. On this basis, three distinct styles of ejecta emplacement can be characterized that reflect the response of individual ejecta particles to vortical winds created by the outward-moving ejecta curtain. Ejecta ramparts result from sudden deposition of coarser clasts sorted and suspended by these winds. Deposition occurs as the thinning ejecta curtain no longer can generate the recovery winds. This style of "wind-modified" emplacement represents minimal ejecta entrainment in the atmospheric response and is enhanced by a bimodal size distribution in the target. As aerodynamic drag and atmospheric pressure increase, the intensity and carrying capacity of the recovery wind increases. The resulting basal ejecta flow runs off and scours the inner ejecta facies, thereby producing rampart-bordered outer facies beyond the eroded continuous inner ejecta. Such "eddy-supported flows" are observed to increase in run-out distance (scaled to crater size) with increasing atmospheric pressure. By analogy with turbidity flows, this crater-scaled distance should increase as $\sqrt{R}$ for a given atmospheric pressure and target lithology. As crater size increases, the turbulent power in the atmospheric response increases. Self-sustaining ejecta flows eventually develop as excessive turbulent power entrains more ejecta and further increases the carrying capacity. Such "auto-suspended flows" result in much greater run-out distances which no longer follow a simple $\sqrt{R}$ scaling relation. Target composed of low-density (0.7 g/cm^3) mirco-spheres (100μ) dramatically demonstrated that both ejecta ramparts beyond the inner facies and much farther auto-suspended flows can develop around the same crater.

Present conditions on Mars are ideal to test these laboratory results. Although tenuous, the present martian atmospheric circulation generates and sustains dust storms with wind velocities (10 m/s) much lower than the expected vortex velocities (>100 m/s) expected to be generated by the outward moving ejecta curtain. Moreover, the diverse geologic history has produced lithologies ranging from solid, massive basalts to easily eroded fine-grained air-fall deposits. The wide range in ejecta sizes reflecting different target lithologies far exceeds the effects of elevation and cyclic changes in atmospheric pressure. Application of the laboratory results to this planetary-scale environment and setting reveals that many of the characteristics commonly ascribed to buried water also can be accommodated by variations in target lithology, i.e., grain size (1, 2, 3). Consequently, increasing ejecta run-out with increasing crater size need not indicate excavation of larger quantities of volatiles at depth but the increased role of ejecta entrainment due to increased turbulence from recovery winds. Such conclusions do not disprove the existence of near-surface water but imply that the role of water in ejecta emplacement may have been a contributing, rather than controlling, factor in many of the ejecta emplacement styles. Consequently increased ejecta run-out with latitude could reflect the increased abundance of aeolian-sorted materials in the ejecta. Nevertheless, near-surface volatiles (including chemically bound water) released by frictional heating of impacting ejecta or entrained secondary debris should significantly enhance the autosuspension process and produce distal ejecta lobes with large run-out distances. Buried water should principally affect remobilization of inner, ballistically emplaced ejecta facies.

While fluidized facies on Mars would be composed of sand-size particles, analogous facies on Venus could contain meter-scale blocks (1), thereby more resembling a rock avalanche. On the basis of inferences drawn from experiments, craters on Venus should not be engulfed by ejecta fall-out (3) but should exhibit fluidized inner facies surrounded by thin distal channelized flows.The inner ejecta facies reflect emplacement by atmosphere-entrained debris flows collapsing from a nearly vertical ejecta wall, similar to martian craters formed in sedimentary deposits. Additionally, turbulence and flow separation will create ejecta-entrained atmospheric turbidity currents with much greater run-out distances and complex channelized forms. These late-stage ejecta deposits should superimpose signatures of early-time atmosphere-impact interactions and high temperature projectile/target phases.

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